Center of Accelerators
and Nuclear Analytical Methods

STATUS REPORT
ISOCHRONOUS CYCLOTRON U-120M
CYCLOTRON TR-24

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EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

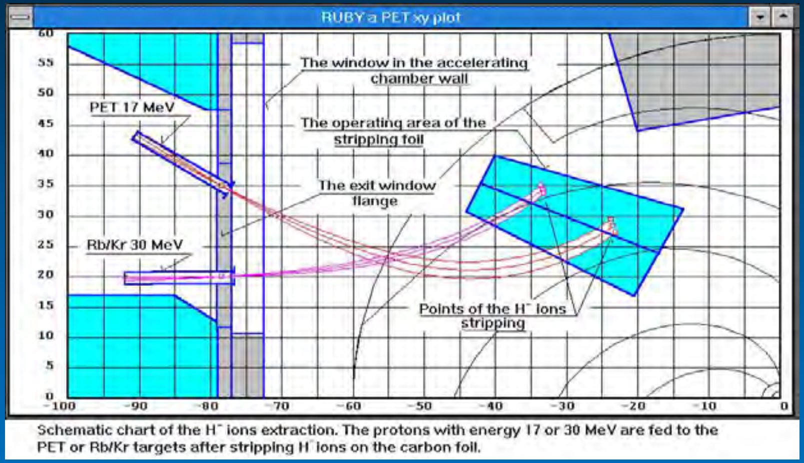
U-120M - HISTORY AND THE MILESTONES

- Isochronous cyclotron U-120M (K = 40, light particles p, d, $^{3}He^{+2}$, $^{4}He^{+2}$, beam extraction by means of electrostatic deflectors) designed and completed in the LJaP division of JINR in Dubna, the former USSR, 1977
- design and construction of the beam line system (new design of quadrupoles, magnet mono-chromator, bending magnets OM1, OM2). NPI, 1979–1982
- axial injection system, NPI, 1990–1994
- **project of acceleration of negative ions, new beam line, NPI, 1992–1996**
- new control system, NPI, 1995–1996
- mathematical model of the cyclotron, beam dynamic simulation, continuous development, NPI, since ~ 1980
- new cooling system, NPI + external company, 2002
- **floods in 2002**
- central LN_2 distribution, NPI + external company, 2006
- new dee with holes for improving evacuation, NPI, 2007

A FEW PICTURES FROM THE PAST

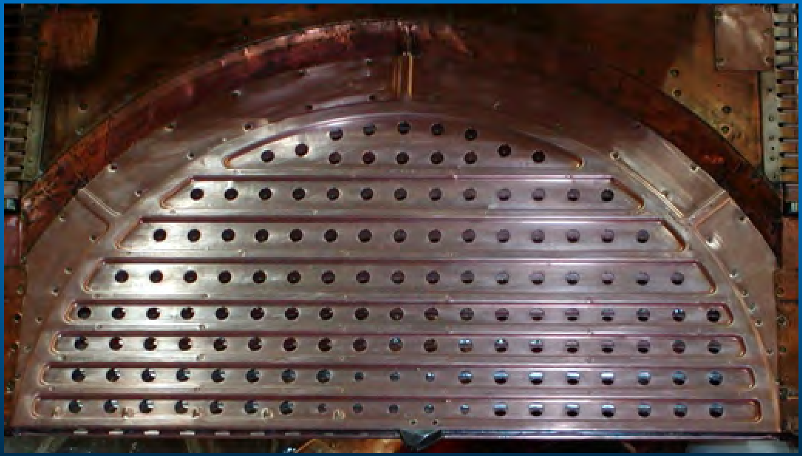
Installation of U-120M in 1976

Very first simulations of H⁻/D⁻ extraction 1992



Floods in 2002 water level

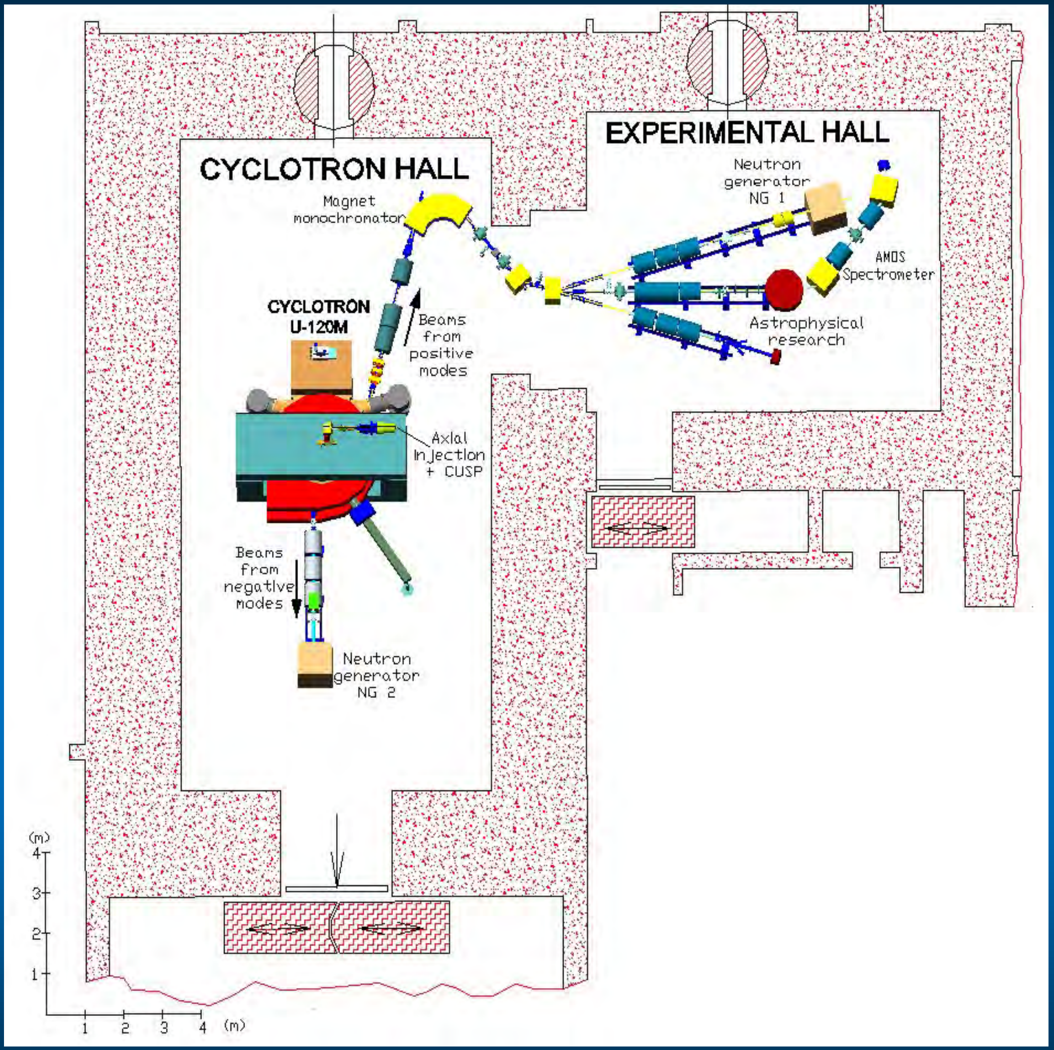
New dee with holes 2007



- Lower beam losses (approx. 20 %)
- Shorter time for evacuation

ISOCHRONOUS CYCLOTRON U-120M

Experimental layout

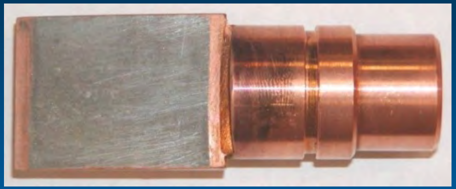


Beam parameters

ions	beam location	energy (MeV)	max. current (μA)
p	int. beam	2–37	> 200
p	ext. beam	6–25	5
H^-/p	ext. beam	6–37	40–30
d	int. beam	2–20	> 80
d	ext. beam	12–20	5
D^-/d	ext. beam	11–20	25–15
$^3He^{2+}$	int. beam	3–55	20
$^3He^{2+}$	ext. beam	18–52	2
$^4He^{2+}$ (α)	int. beam	4–40	40
$^4He^{2+}$ (α)	ext. beam	24–38	5

INTERNAL SOLID TARGETS

1°–1.5°



- ^{67}Ga
- ^{201}Tl
- ^{111}In

1°–1.5°

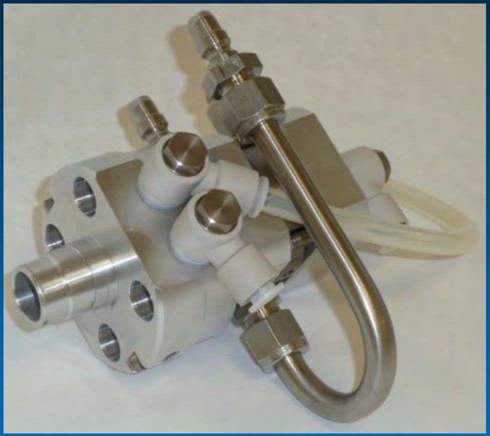
- ^{211}At
- FND
- ^{64}Cu

revolving

- ^{211}At
- Cu isotopes

EXTERNAL TARGETS I

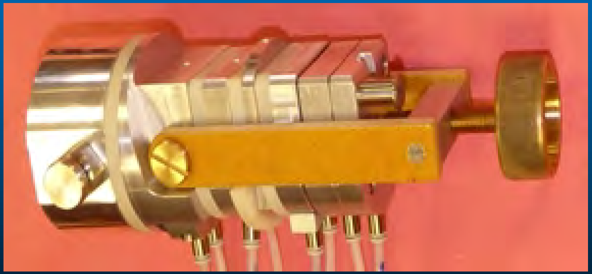
Liquid targets



- ^{18}F
- ^{68}Ga
- ^{86}Y
- FND production

Gas targets

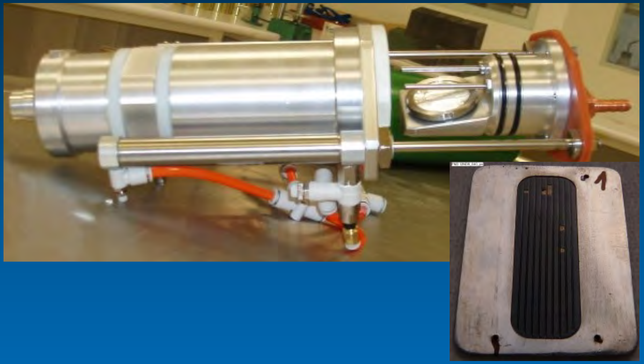
- ^{81}Rb
- ^{83}Rb
- ^{123}I



- excitation functions
- ^{99m}Tc
- calibration sources
- FND production

EXTERNAL TARGETS II

10° target holder

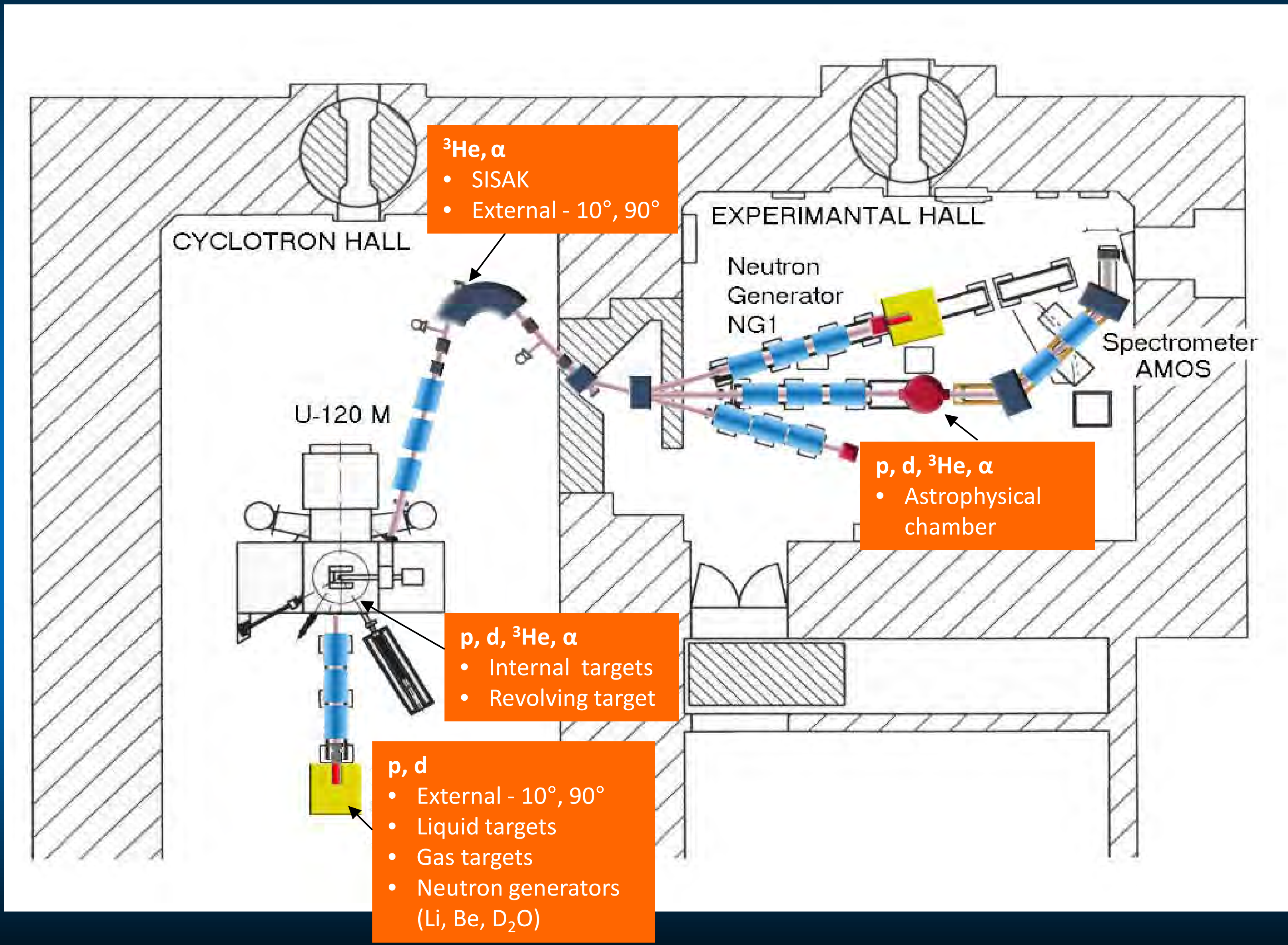


- FND
- ^{124}I
- ^{86}Y

sample holder

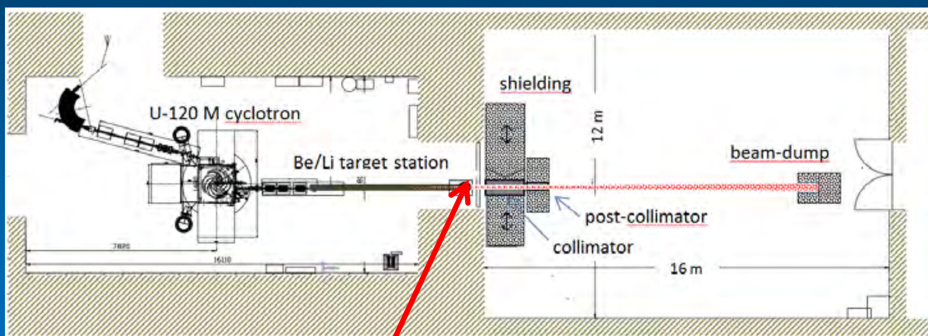
- biological samples
- testing of electronic equipments

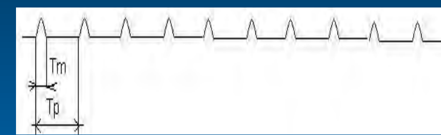
POSITION OF THE CURRENTLY USED TARGETS



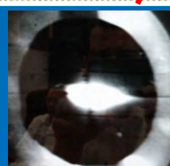
Collimated neutron beam on U-120M cyclotron for nTOF

- for collimated neutron beam a flight path (15 m) to beam dump available (low backscattering background)
- high intensity flux and suitable energy selection under the existing time-structure of cyclotron beam

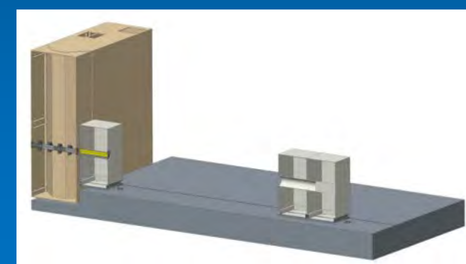




Tm = 4.6 ns (fwhm)
Tp = 38.95 ns
Ep = 36 MeV
Tm/Tp ratio ~ 1 : 6.5



Beam spot at the proposed target position



- transportable shielding (blocks), collimated beam size: from diam. 3 cm to 25 cm

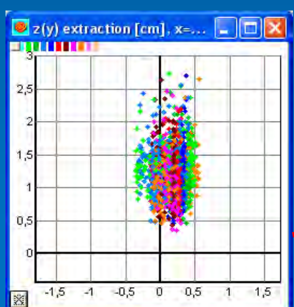
- beam simulation with AGILE, experimental verification of vertical resp. horizontal beam position, beam spot
- fixation of collimator position in movable shielding doors

- p+Be (thick target) source reaction
- white spectrum neutron beam up to 35 MeV, ≤ 7 10^7 neutrons/sec, local irradiation
- p+Be/Li (thin target) source reactions
- QM neutron beam 20-35 MeV range ≤ 3 10^6 neutrons/sec, rough TOF energy selection

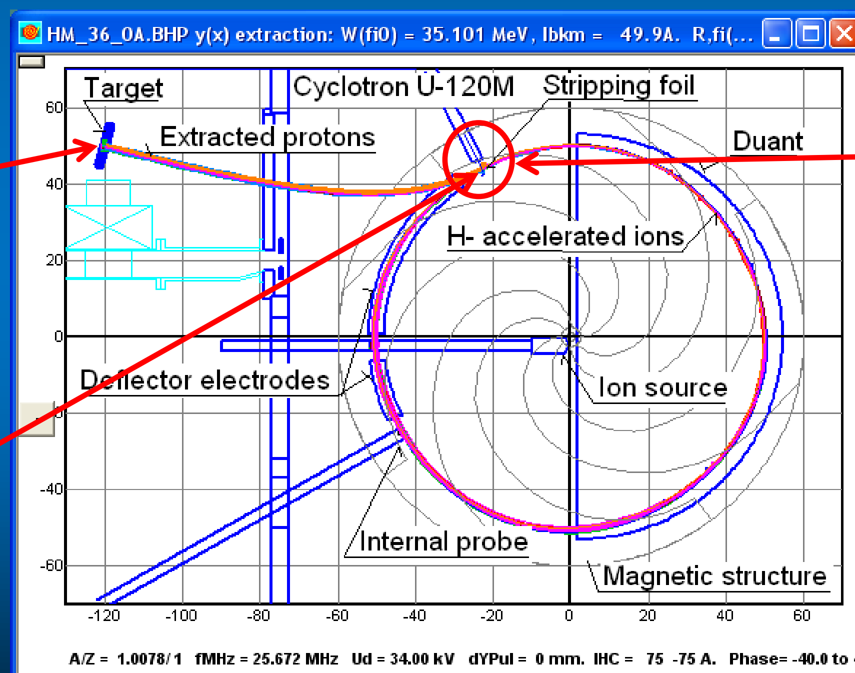
- LC&FNG becomes competitive to neutron facilities at Uppsala and Leuven-le-Neuve
- Shielded acquisition stations will enable to measure differential CS observables - more sensitive tests of CS models and data libraries
- extraction of the accelearted beams into the adjacent experimental hall – low electromagnetic noise

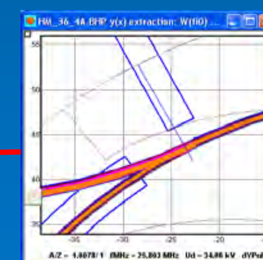
Project of multi-orbital beam extraction (bunching system) at U-120M for nTOF

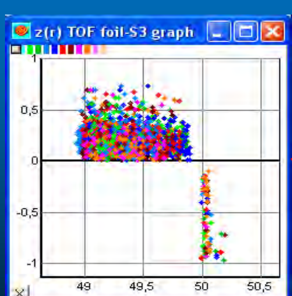
- acceleration of H^- ions
- deflection of the beam orbits in the deflector region (48 – 50 mm) by means of the deflection electrodes supplied with the HV pulse, ~10kV, rising resp. falling time ~ 12ns
- multi-orbital accelerated ion beam extraction i.e. increase of the number of extracted ions
- extraction of the proton pulse by the carbon stripping foil ($H^- \longrightarrow p$)
- neutron production target (Be) positioned outside of the vacuum chamber



Extracted ions







Deflected ions on the stripper

Tm = 4.6 ns (fwhm)

Tp = 38.95 ns

Ep = 36 MeV

Tm/Tp ratio ~ 1 : 100

UTILIZATION OF THE U-120M BEAMS

- Measurements of S-factors for reactions important in nuclear astrophysics by indirect methods (particularly with worldwide rarely accessible beam of $^{3}He^{2+}$) and study of reaction mechanisms – Jaromír Mrázek
- Nuclear reaction data measurements (excitation functions and thick target yields of deuteron-induced reactions on ^{93}Nb, Fe isotopes, ^{89}Zr, ^{27}Al, ^{nat}Ti, ^{89}Y) – Ondřej Lebeda
- Production of novel medical cyclotron radionuclides (^{61}Cu, ^{64}Cu, ^{99m}Tc, ^{124}I, ^{52}Mn, ^{197}Hg) and calibration sources and tracers (^{56}Co, ^{83}Rb, ^{90}Nb) – Ondřej Labeda
- Routine irradiation for production of ^{18}F for FDG, $^{81}Rb/^{81m}Kr$ generator – RadioMedic
- Material modifications with accelerated ion beams (i.e. production of fluorescent nanodiamonds)
- Irradiations of biological samples – Marie Davídková
- Electronic device and component (integrated circuits, memories etc.) testing, i.e. radiation hardness measurement under specific irradiation conditions – Filip Křížek
- In connection with target stations developed at the FNG, the cyclotron is a unique and powerful source of highly intense fast neutron beams – Jan Novák

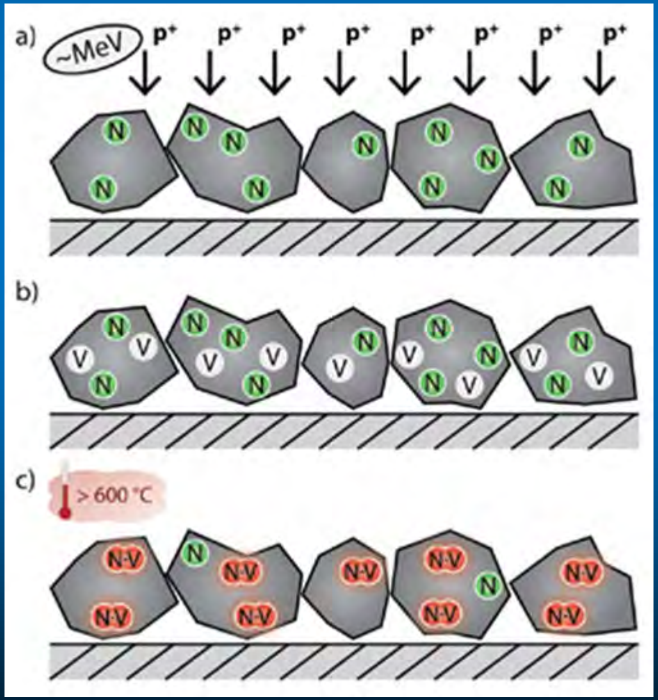
BEAM TIME ~ 3000 hours/year

Preparation of fluorescent nanodiamonds (FNDs)

Institute of Organic Chemistry and Biochemistry, Czech Academy of Sciences, Czech Republic
Nuclear Physics Institute, Czech Academy of Sciences, Czech Republic

Creation of NV centers:

Nanodiamond: biocompatible carbon nanomaterial (Ib HPHT), powder or aqueous solution, variable size ranging from ~ 5 to 100 nm

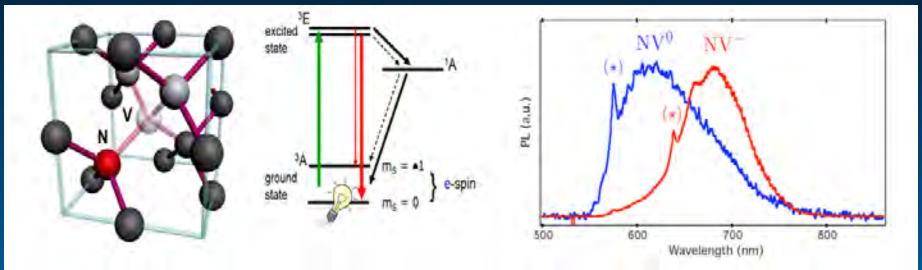


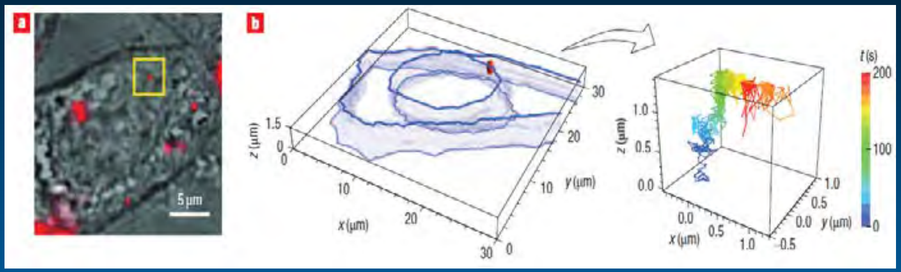
irradiation with accelerated ions (H^+, D^+, alpha), energies 6–40 MeV (depending on used particle, type of target)

vacancies created by irradiation

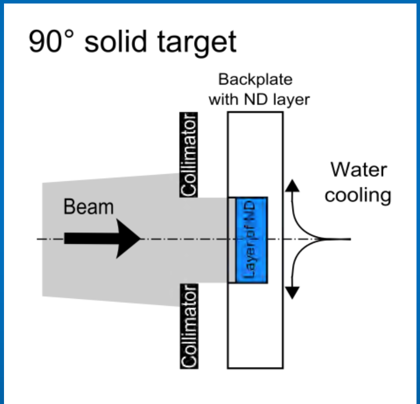
formation of NV centers by high temperature annealing ~ 900 °C

Photoluminiscence centers NV^0, NV^-

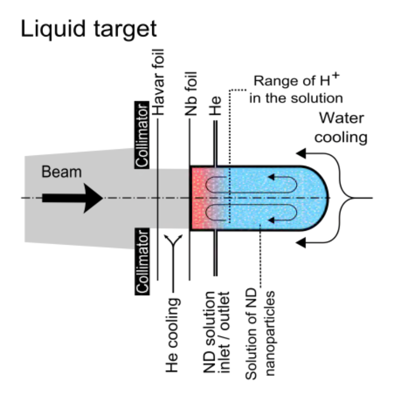




Proton irradiation of a compressed solid ND pellet



Proton irradiation of 5% ND aqueous solution



Bioimaging, biolabeling, substitution of quantum dots, single particle tracking, nanoscale magnetic field sensing etc.

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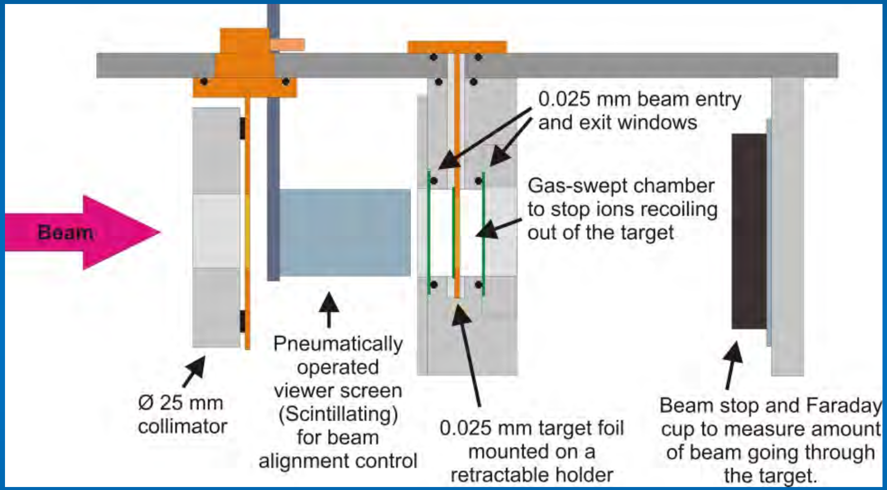
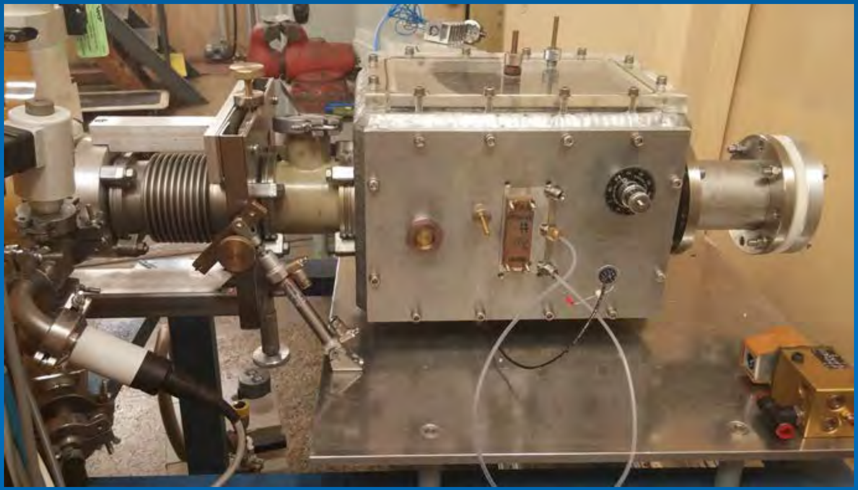
Initial tests of UiO target system and gas-jet transport for on-line chemistry of homologues of the SHE

Department of Chemistry, Univ. of Oslo, Norway
Czech Technical University, Prague, Czech Republic
Nuclear Physics Institute, Academy of Sciences, Řež, Czech Republic





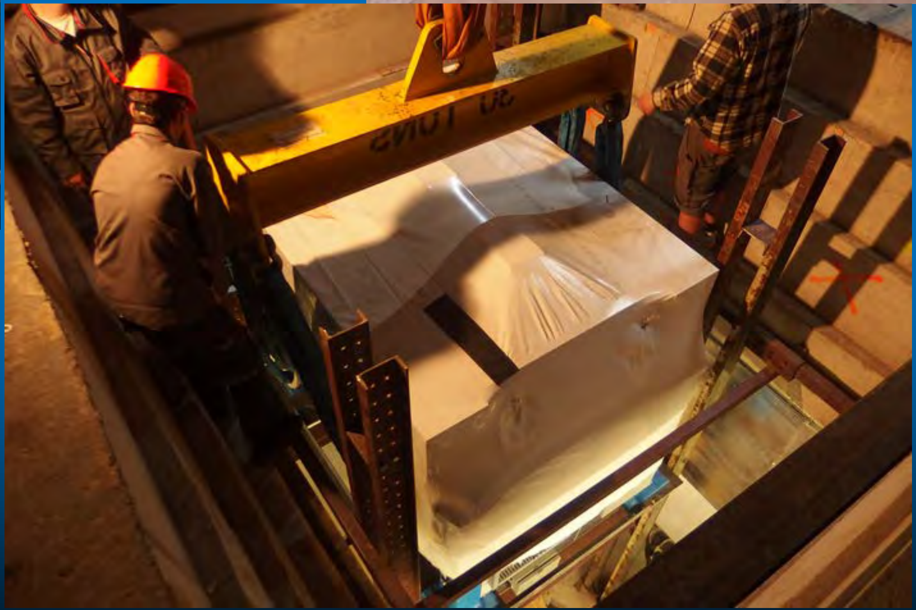
Target:	^{nat}Yb	^{nat}Lu	^{nat}Zr	^{nat}Hf
Main product and $T_{1/2}$:	^{169}Hf (3.3 m)	^{174}Ta (1.0 h)	^{90}Mo (5.7 h)	^{177}W (2.3 h)
Most useful γ-ray:	493 keV	207 keV	257 keV	493 keV
Homologue of:	Rf	Db	Sg	Sg

PROJECT OF THE NEW CYCLOTRON TR-24 (2013–2015)

11/2012	Start of the project
11/2012	Start of the building reconstruction
01/2013	Contract with the ACSI
09/2012	Cyclotron vault constructions, shielding MCNPX simulations
04/2014	End of the building reconstruction
09/2014	Installation TR-24
05/2015	Installation technology of TR-24
08/2015	End of the technology preparation
09/2015	Site Acceptance Test

CONSTRUCTION OF THE SITE

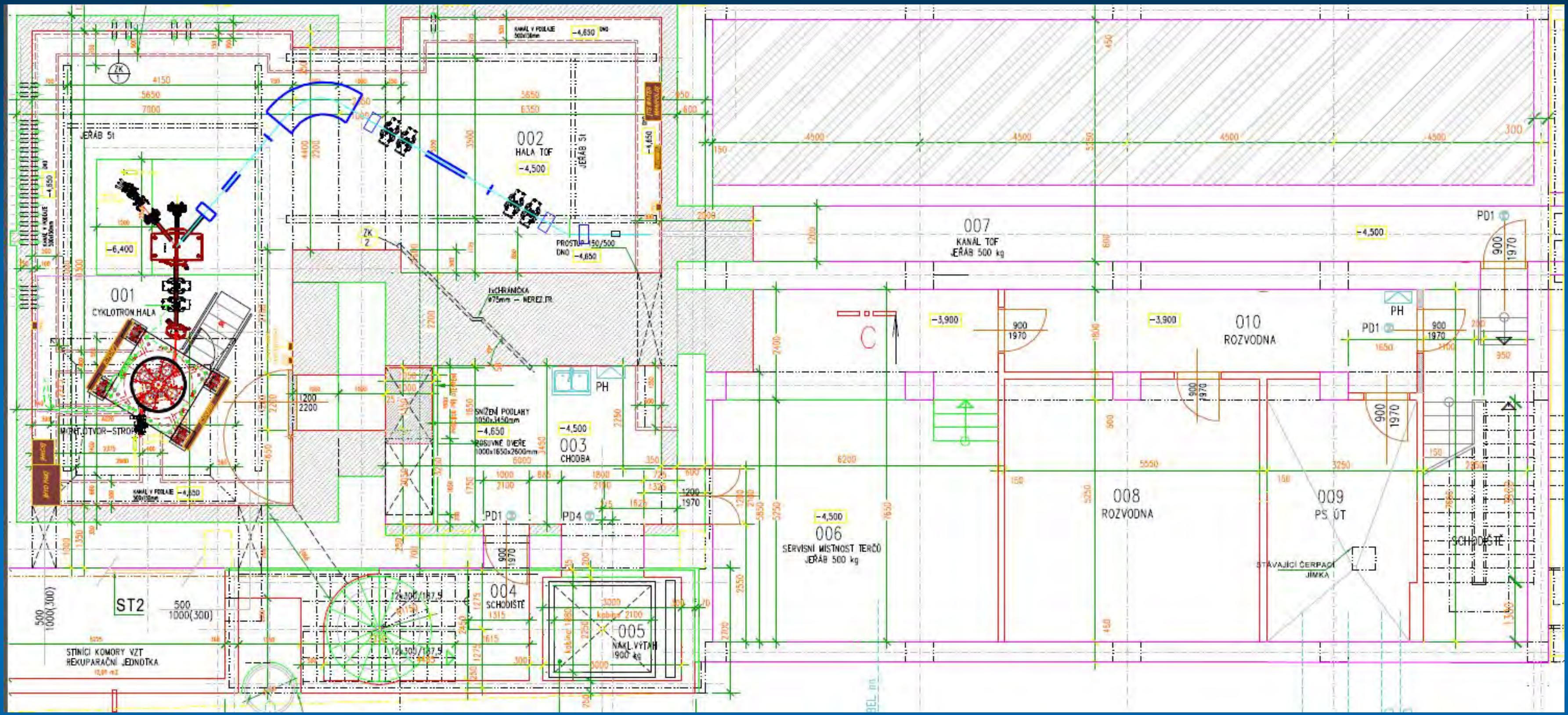
TR-24 INSTALLATION
September 2014



BASIC PARAMETERS OF THE TR-24 CYCLOTRON

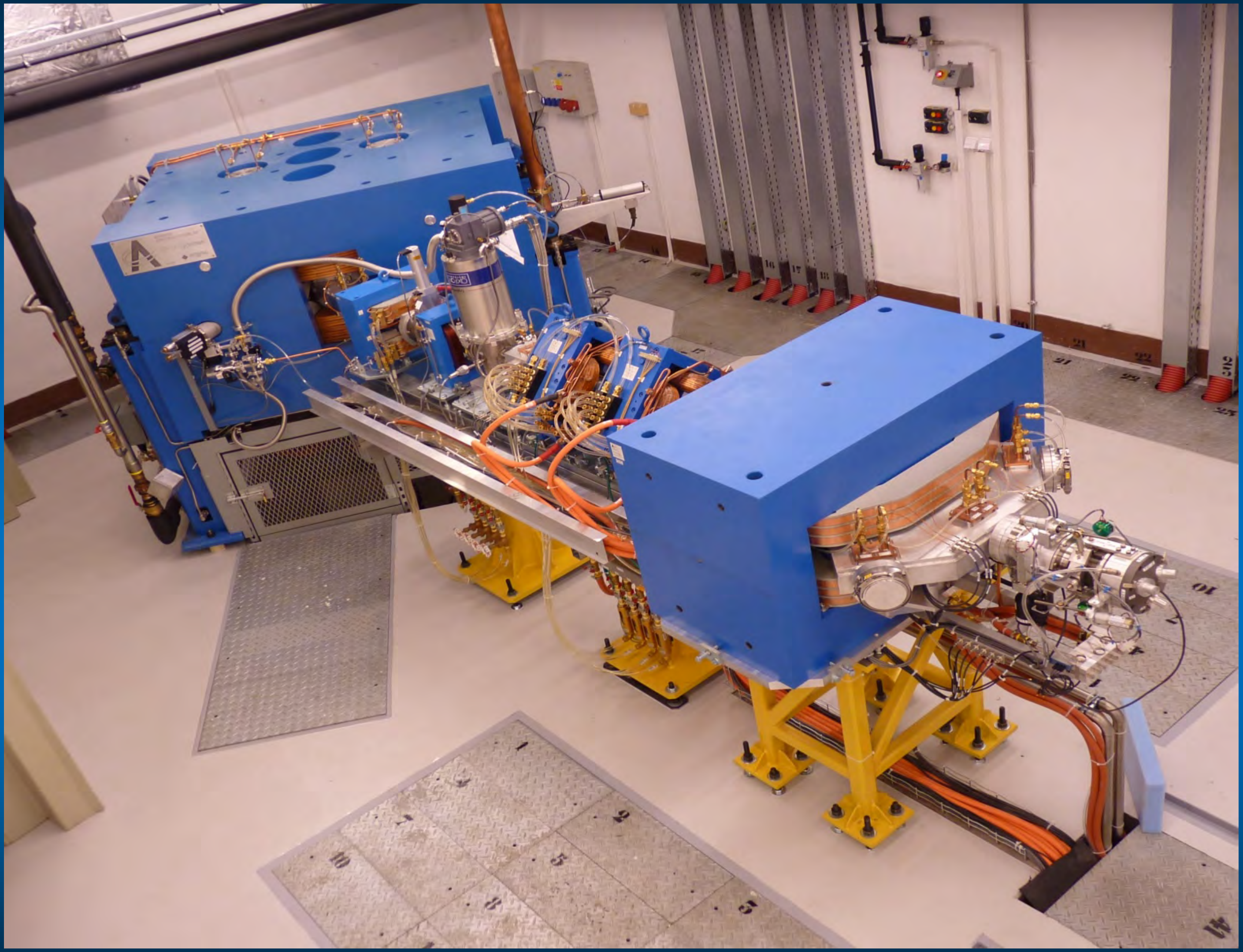
TR-24 – Advanced Cyclotron System Inc. (Canada)	
Proton energy range	18–24 MeV
Max. proton beam current	**300 μA**
Acceleration frequency	85 MHz
Acceleration voltage	50 kV
H^{-} Ion source	Multi-CUSP
Simultaneous beams	2
Weight	25 t
Dimensions	1.8×1.8×2.5 m
Power	180 kW
Middle magnetic field	1.4 T

TR-24 LAYOUT



001
CYKLOTRON HALA
002
HALA TOF
JEŘÁB 5t
003
CHODBA
004
SCHODIŠTĚ
005
NÁKL.VÝTAH
006
SERVISNÍ MÍSTNOST TERČŮ
JEŘÁB 500 kg
007
KANÁL TOF
JEŘÁB 500 kg
008
ROZVODNA
009
PS ÚT
010
ROZVODNA
SCHODIŠTĚ
ST2
STÍNICÍ KOMORY VZT
REKUPERAČNÍ JEDNOTKA
STÁVAJÍCÍ ČERPACÍ JÍMKA
SNÍŽENÍ PODLAHY
POSUVNÉ DVEŘE
PD1
PD4
PH

TR-24 COMMISSIONING – October 2015



RESEARCH PROGRAM

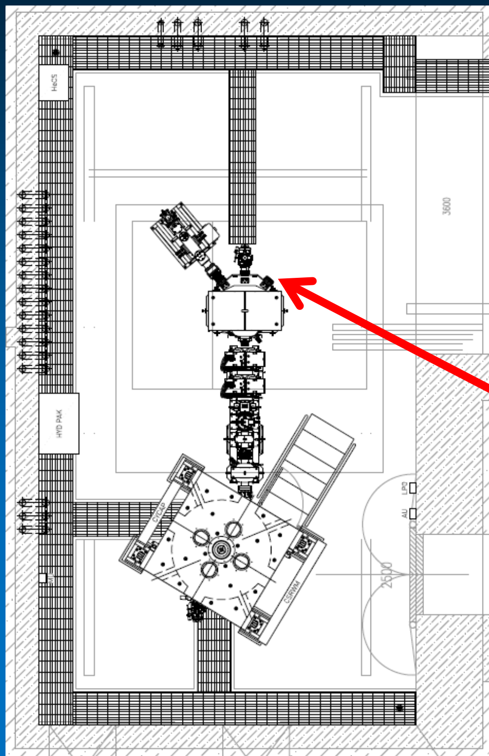
- Experiments and research projects associated with the generation of high fluxes of fast neutrons:
  - measurements of observable cross sections induced by fast neutron
  - nuclear data for new fusion-fission and advanced fission systems

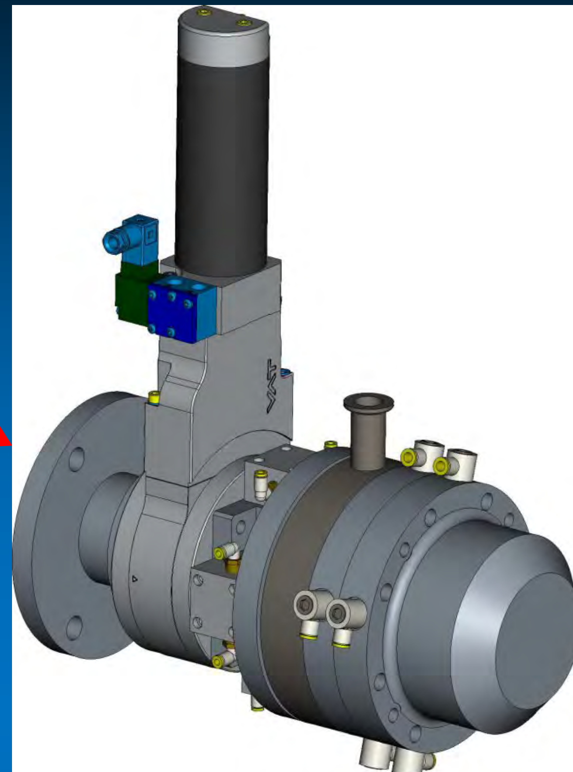
- Production of novel medical radionuclides and new ways of production of established radionuclides, including casual production of tracers and calibration sources, e.g.
  - longer-lived radionuclides e.g. ^{44}Ti, ^{67}Cu, ^{89}Zr and ^{68}Ge
  - feasibility study of implementing direct production of ^{99m}Tc via (p,2n) reaction as an viable alternative to reactor-produced generator $^{99}Mo/^{99m}Tc$.

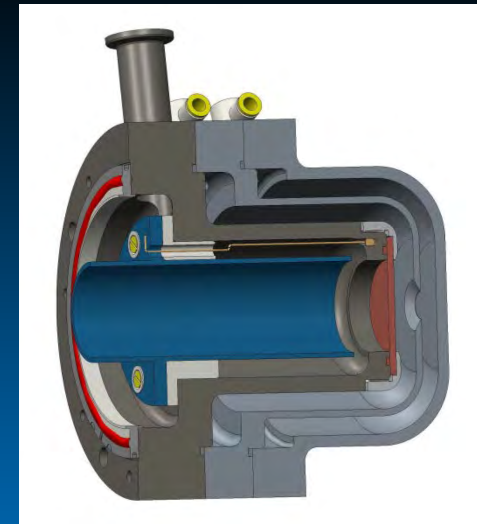
UPGRADE OF THE TR-24 INFRASTRUCTURE

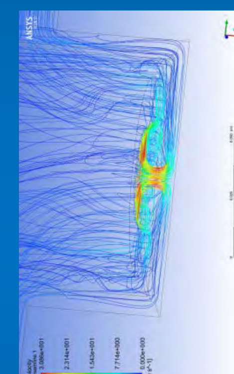
- In cooperation with FNG group - development of high-power (7.2kW) neutron target, neutron flux density ~ $3*10^{12}$ n/s/cm^2.
- In cooperation with Department of Radiopharmaceuticals - development of the high-power targets for production of novel research radionuclides and generators.

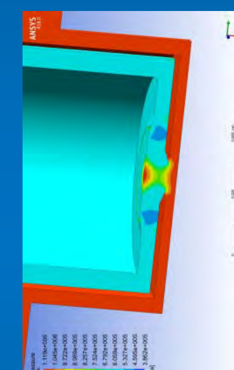
High power neutron (Be) target











- static target (beryllium disk, thickness 4 mm, φ 40 mm))
- irradiation consideration (insertion of samples - reach maximal neutron fluxes, open at forward direction to minimize limitation on dimensions of samples and installation associated equipment under irradiation
- proton beam - up to 7.2 kW heat power (0.9 to 3.5 kW/cm^2 depending on the beam focus)
- total flux densities ~ $3*10^{12}$ n/cm^2/s along the axis of irradiation zone for the beam spot of φ 1,6 cm
- target-cooling arrangement based on submerged jet technique
- simulations with ANSYS code (HVM Plasma cooperation)
- remote handling set-up to adopt shielding box for out-of-beam target storage

THANK YOU FOR YOUR ATTENTION !